DEVELOPMENT OF A TESTING PROCEDURE USING CONE INDEX TO ALLOW FOR OPTIMAL TIRE PERFORMANCE

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ABSTRACT

This project discusses the design, fabrication, and evaluation of a Soil Cone Penetrometer that is to be used to test tracks designated for modified tractor pulling. The penetrometer measures the force required to penetrate a soil and provides a recommended tire pressure specific for the conditions present at the point in time.

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INTRODUCTION

Background

The sport of tractor pulling in America began in the early part of the 20st century in the Eastern part of the United States in Bowling Green, Kentucky. Throughout the years competitors have tried to modify their vehicles to outperform their competition. One of the easiest modifications a tractor puller can do is adjust the tire pressure depending on track conditions. Small adjustments could mean better traction resulting in better performance. Decisions on what tire pressure to use are determined by which soil type the track consists of.

Justification

Because of the common variability of the track conditions, predicting the cone index of a soil is not easily done, however, there are tools that can assist with this process. These tools are called soil penetrometers. Penetrometers typically measure the force required to penetrate the soil and how far the penetration goes into the soil. Standard units usually measure soil hardness from the surface to the root zone of the plants which can commonly range anywhere from six inches to three feet. These units are usually very expensive and only used for scientific purposes. A smaller penetrometer could be developed to be used by the Cal Poly Tractor Pull Team to assist with determining soil hardness for considering tire pressures. The penetrometer would only be required to penetrate the top portion of the track since the tractor tires only interface with the top soil layers. The device would be simple enough for any member to use. The information would then be recorded in the log book and used for record keeping.

Objectives

The main objectives of this project include:

1. Create a Soil Cone Index penetrometer that meets ASABE standards for a design
2. The device will be used to test any track that the pull team competes on
3. The device should be easy enough to operate so only one person is required to collect data
4. A testing procedure will be developed and incorporated into the log book

The completion of this project will benefit the Tractor Pull Team allowing any member with any amount of experience to make critical decisions that directly influence performance of the tractor. The data will be able to assist the team with future records and data collection.

LITERATURE REVIEW

Determining tire pressure has always been a focal point for tractor pulling. The slightest change in tire pressure could have a great effect on the outcome of the tractor's performance. This is why a soil cone penetrometer tool should be developed in order to assist pullers with the determination of their tire pressures. Because soil properties for each track will be vastly different from one another (Argabright, 2009), it is important to have a penetrometer that will be able to be used at any location.

Cone Index and Soil Properties

Cone index (CI), is a measure of the penetration resistance of a soil. It is affected by many factors including soil density, moisture content, and soil type. The cone index is a measure of the force per base area required to penetrate this cone into the soil. The cone index provides some indication of the shear resistance of the soil which in turn depends upon the strength properties of the soil (Ayers and Perumpral 1982). Cone index varies directly when being related to bulk density and depth (Kumar et al, 2006). Compaction of the soil from tires also effects bulk density therefore effecting cone index. The more a soil is used, the greater it is compacted which in turn creates a higher density (Hughes, 2009). The greater compaction creates less traction (Hayes and Ligen, 1981). This project will develop a procedure that will be able to determine the cone index for a particular soil regardless of its properties. The easiest way to determine the CI is to use a simple formula using cone base area and force applied.

By using this information one can develop a graph similar to Figure 1, which shows the cone index pressure in relation to the depth penetrated. A graph containing multiple soil types will allow one to determine the proper tire pressure to use in relation to soil hardness.

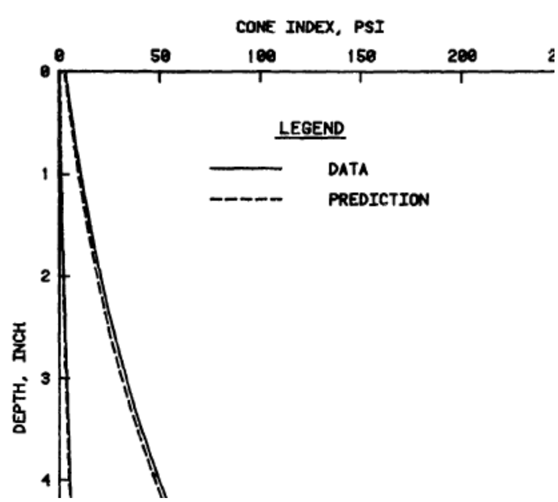

Figure 1: Graph of CI compared to Depth (Balad and Rohani, 1981)

Penetrometers

The penetrometer is the main tool used when determining soil cone index. The soil cone index penetrometer is made with specific guidelines to ensure its function is properly used and that calculations are accurate. The proper angle of cone for a penetrometer is 30° (ASAE 1994). Figure 2 represents a traditional penetrometer. For the purpose of making the calculations easy to manage, the cone base should have an area of 0.5 in^2 (Balad and Rohani, 1981). When using the tool in testing, it's essential to perform the test at a constant rate (ASAE 1994). The rate should be around a penetration of one inch per second. The device will be able to measure depth, as well as force of insertion into the soil.

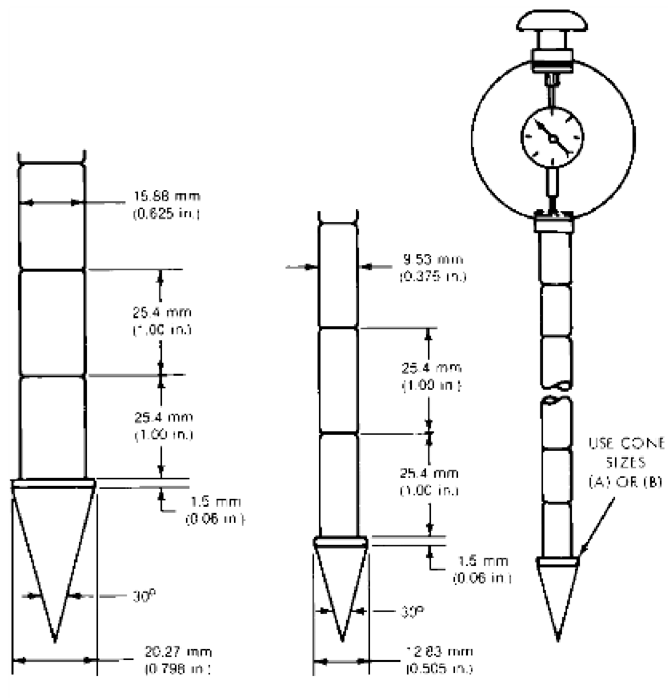

Figure 2: Standard Penetrometer (ASAE 1994)

Tire Pressure and Traction

Tire pressure is the most important factor, other than weight distribution, that one can adjust on the tractor to improve performance. Lower tire pressures were recommended for pulling loads. The lower inflation pressure of 6 psi generated about 25% more pull than the higher test pressure of 18 psi (Raper, 2008). Lowering the air pressure increases the amount of rubber gripping the soil, and therefore increases the traction of the vehicle. Halving the air pressure tends to double the amount of tire touching the terrain (Bickford, 2010). The tires on Mustang fever have been custom cut to try and achieve maximum performance through surface contact with the soil by using the optimal angle of tread which is 23° (Firestone Tires, 2010).

PROCEDURE AND METHODS

Design Procedure

The main design standard for this senior project was to follow the design requirements as stated by ASAE for Soil Cone Penetrometers. This meant having a 30° cone to penetrate the soil with a base area of 0.50 square inches. All other aspects of the design were designed around the main components of the penetrometer. The completed design is shown in Figure 3 below.

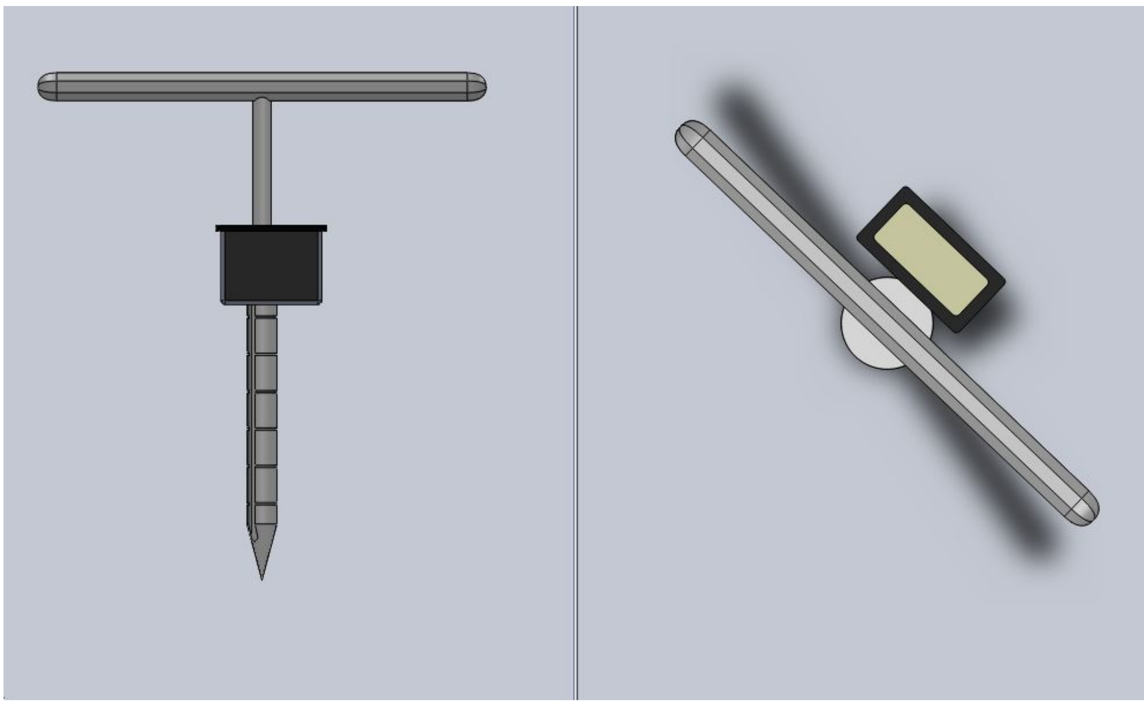

Figure 3: Final Design of the Soil Cone Penetrometer showing the display mounted

Penetrating Unit. The penetrating unit for the penetrometer was the main component in which all other parts were built around. The unit needed to have the 30° cone. Normal Soil Cone Penetrometers are built to be able to penetrate up to three feet of soil. Because the penetrometer was going to be used on tracks, it only needed to be able to penetrate a max depth of eight inches. To allow for students using the device to know how far they had penetrated, one inch increments were placed on the unit. A keyway was made to allow for a depth stop to be set for testing so that the user knows how far they have penetrated during the test.

Load Cell. The load cell for the unit needed to be able to handle the wide range of forces that would be experienced while using the device on a wide variety of tracks. It was decided that a load cell with capabilities of measuring a maximum force of 250 pounds would suffice for the maximum force needed to measure Soil Cone Index. The reasoning for this decision was that an average person would not be able to produce forces greater than 250 pounds. This meant the range of the load cell would not need to measure beyond 250 pounds. Any force exceeding the range of the load cell would require that the tire pressure be set at the maximum pressure recommended. The load cell can be seen in Figure 4.

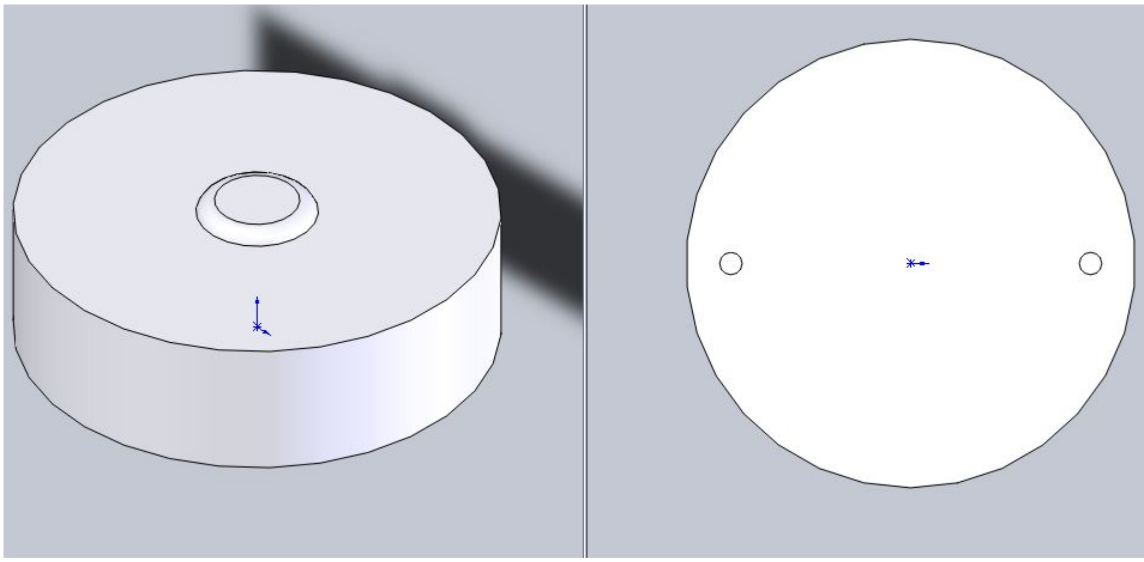

Figure 4: The load cell. The photo on the left is an isometric view. The photo on the right shows the mount screw holes on the bottom of the cell.

Housing for the Load Cell. The housing unit could not be designed until the load cell was decided upon. The housing would hold the load cell in place and keep it from moving around during testing. It would also protect the load cell from getting damaged during transit or handling. The load cell came with a set of mounting screws that would hold the load cell securely in position. The housing had to allow for the mounting screws to access the bottom of the load cell so it could be mounted in place (Figure 5).

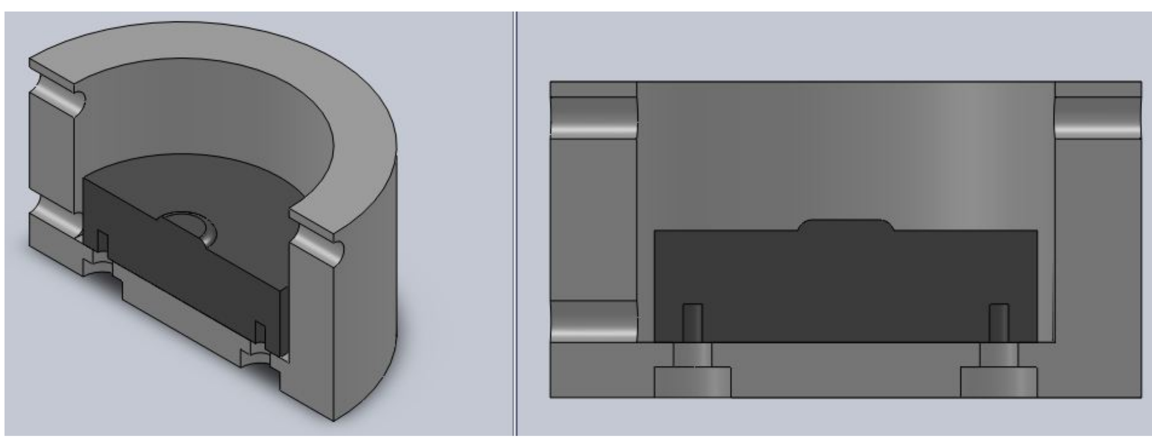

Figure 5: The figure shows the sectional view of the housing unit with the load cell in place.

Housing Unit Cap. The cap needed to fit within the top portion of the housing and stay secure. The idea was to make a cap that fit into the top of the load cell housing and stay in place with set screws. A hole was to be made in the center of the cap to allow for the handle unit to fit through to be able to interact with the load cell (Figure 6).

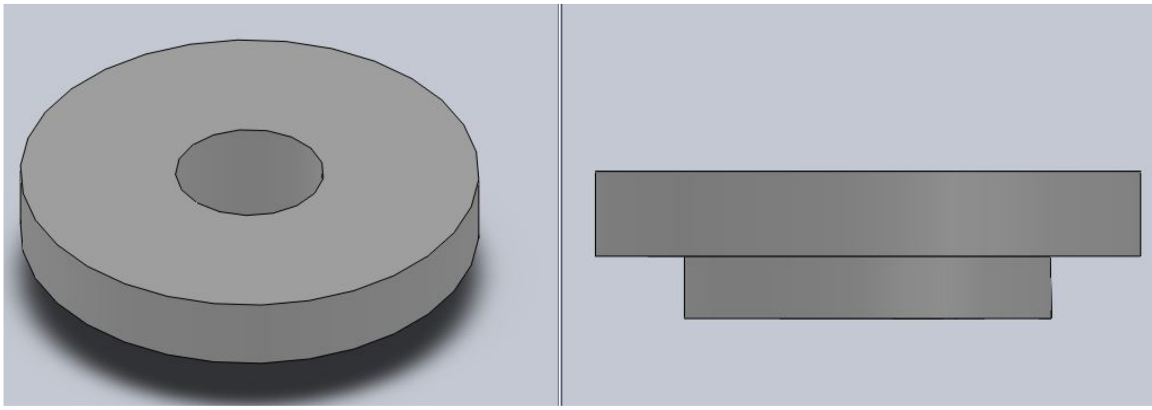

Figure 6: The cap as designed in SolidWorks

Handle Unit. When designing the handle unit, the actual handle needed to be wide enough that someone could use two hands while operating the penetrometer. The stem of the handle had to be large enough to handle the loads that would be experienced during operation with minimal deflection.

Bushing for Handle. A bushing needed to be made to ensure that the handle did not move around while testing. The bushing would keep the handle stem perpendicular to the load cell to make sure the forces were directly applied in a perfectly vertical manner as seen in Figure 7.

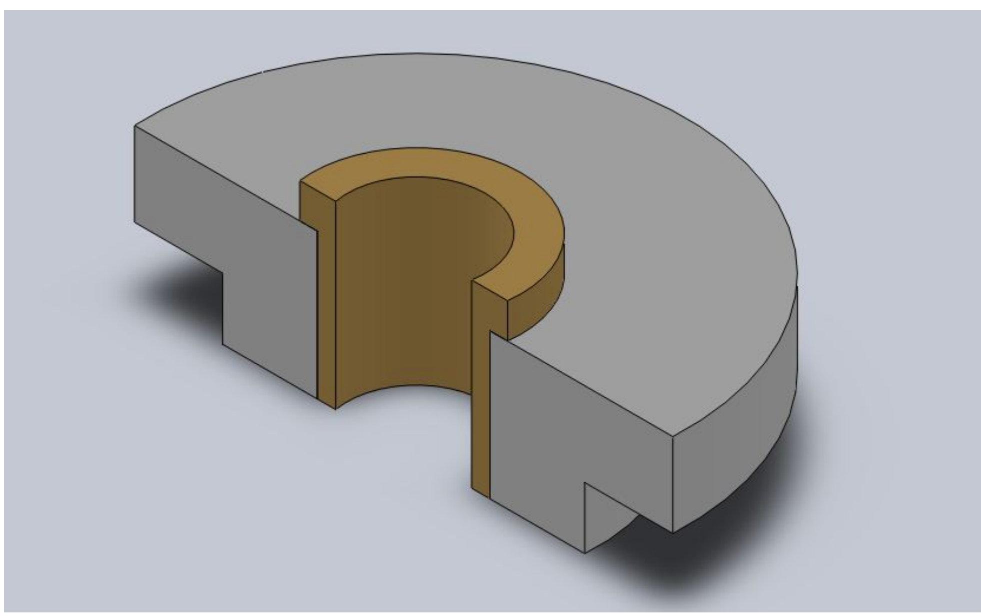

Figure 7: The cap with the bushing in place

Display Unit. A digital display was chosen to read out the outputs of the load cell. The digital display was chosen over a mechanical display because the digital display would read out exact values large enough for someone to see clearly while testing. The display is shown in Figure 8. Another major factor when deciding on the type of display was that the one chosen only required 9 volts of power to function. The Cub4V display was chosen to use because it was inexpensive and met the suggested requirements.

Figure 8: Red Lion Cub4V display unit.

Construction Procedure

The construction portion of the project took multiple steps. Each piece was constructed separately then put together at the end of the fabrication. The machine most utilized in the machining process was the lathe.

Penetrating Unit. The material used for the penetrating unit was 1 inch hot rolled round stock. A piece of 12 inches was cut to length by the band saw. The material was then faced in the lathe and center drilled to be able to machine a length of 9 inches and minimize wobble. The material was turned down from a diameter of 1 inch to 0.798 inches over the 9 inches. The material was faced again to remove the centering hole. The next part of the process was to begin the tapering cut for the cone. The cross feed compound was rotated to the 75º mark to produce a 30º cone (Figure 9). The cut produced a length of 1.49 inches for the cone.

Figure 9: Taper cut being made for the cone of the penetrometer.

The piece was then filed with a fine file to smooth out any rough spots on the material from the lathe work. Sandpaper was then used to produce a clean shine. 1 inch increments were cut into the part using a parting tool. The first mark was placed 2 inches from the end of the cone. The remaining increments were then made off of the 2 inch mark as shown in Figure 10.

Figure 10: Increments being made using the parting tool.

Once the increments were made the penetrating unit cut to the proper length of 8 inches. Next it was placed in the mill to have a keyway milled into it.   After the mill was trammed the unit was placed on parallels to ensure that the unit was machined squarely. Using the Acu-Rite, the center was found on the piece. The keyway was then cut using a ¼ inch end mill 1/8 inch deep as seen in Figure 11.

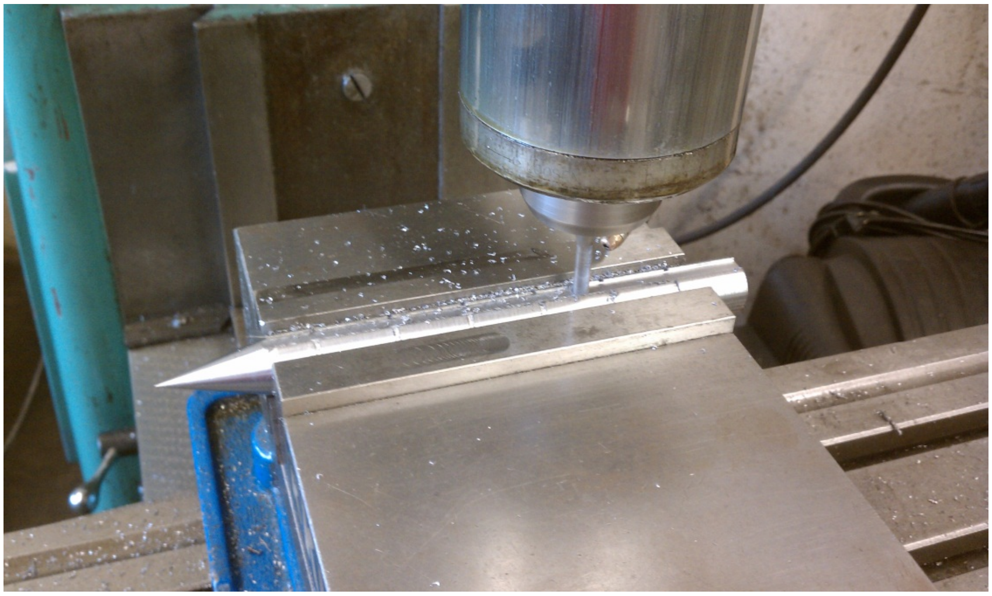

Figure 11: Milling the Keyway into the Penetrating Unit

<u>Housing for the Load Cell</u>. Making the housing for the load cell was the next step in the fabrication process. Solid round stock with a diameter of 1.93 inches was used. The first step was to face the first edge. The piece was then flipped around and placed in the jaws with the use of parallels to ensure the new edge was square with the already machined face. The new face was turned down so that the height of the material was 1.03 inches. The material was then center drilled. A 5/8 inch drill bit was used to create a pilot hole that went 0.85 inches deep into the material which was the desired depth of the housing. A 1-1/4 inch drill bit was then used to widen the hole. A boring bar was then used to open the hole to the desired inside diameter of 1.365 inches (Figure 12).

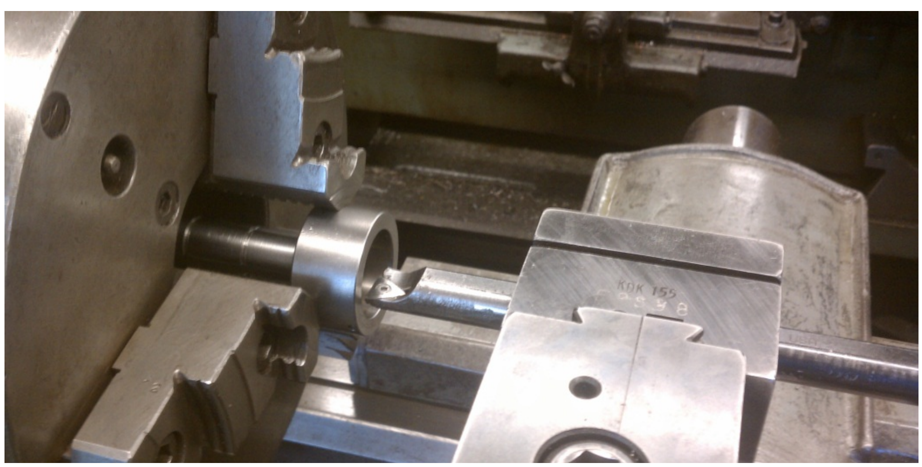

Figure 12: The figure shows the boring bar being used to create the proper ID of the housing unit

All edges were chamfered to eliminate sharp edges. A hole needed to be placed in the bottom portion of housing unit to allow for the load cell cable to be accessible. This task was done using the mill machine with the Acu-Rite system. The hole was centered and drilled ¼ inch from the bottom of the bottom of the housing unit. While still in the mill two holes were drilled into the top portion of the unit to allow for set screws that would hold the cap in place. The holes were drilled out using a #29 drill bit (Figure 13). A single motion on the mill was used to drill both holes. After the holes were drilled, an 8-32 tap was used to thread the holes for the 8-32 x 1/8 inch set screws (Figure 14). The next step for the housing unit was to make mounting holes to allow the load cell mounting screws to secure the load cell. The holes were located ½ inch off of center, 1 inch apart. The initial holes were drilled out using a #29 drill bit. The holes were then recessed using a 1/8 inch end mill so the mounting screws sat flush with the bottom of the housing unit.

Figure 13: Drilling the Set Screw holes

Figure 14: Tapping the holes for the set screws

Cap for Housing Unit. A 0.65 inch thick piece of 1.93 inch solid round stock was cut out on the band saw to make the cap. The first edge was faced and chamfered on the lathe. The cap was then turned around in the jaws and placed using the parallels to ensure squareness to the machined face. Half of the material was turned down to the desired diameter of 1.30 inches to ensure that it would fit inside the top portion of the housing unit. The turned down edge was then faced to width of 0.22 inches to allow for open space between the bottom of the cap and the top of the load cell (Figure 15). A 5/8 inch hole was then drilled through the center of the cap to allow for a bronze bushing.

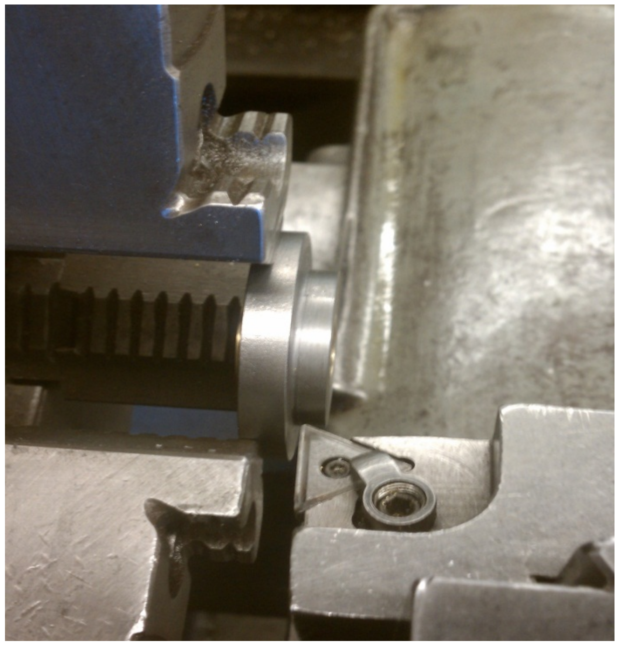

Figure 15: Facing the cap to fit into the housing unit

Bushing. Using ¾ inch bronze round stock, a bushing was manufactured for the handle unit by the processes of turning, facing, and parting. The bushing was turned down to 5/8 inches to fit snuggly into the hole drilled through the center of the cap. A 0.495 inch hole was drilled through the bushing to fit the 0.494 inch handle stem. The bushing was pressed into the cap with an interference fit. The hole was then reamed to allow some clearance of the handle stem for a perfect fit.

Handle Stem. The handle stem was created from a ½ inch grade 2 bolt that was 6 inches long. The head of the bolt was cut off in the band saw. Next the threaded portion of the bolt was cut off to create a piece that was 4.50 inches in length. The stem was placed into the lathe and faced on one edge. A depression bump was created on the end of the stem using free hand lathing. This bump would help create maximum depression on the load cell. A snap ring groove was creating using the grooving tool. The cut was made 0.10 inches from the end of stem on the side with the bump. Once there, an external snap ring was placed.

Handle. ¾ inch octagon stock was used to create the handle. A piece was cut to a length of 12 inches on the band saw. Each end was faced, tapered, and then rounded using free hand machining. The starting taper was made at an angle of 15º and then rounded by freehand (Figure 16). The handle needed to be sand blasted to remove rust and manufacturer scale. To allow for easy welding between the handle and stem, a ½ inch recess was milled into the handle. The handle portion was placed in the mill and centered using the Acu-Rite display. A 4 flute ½ inch end mill was used to cut the recess at a depth of 3/8 inches. This recess allows the stem to be square for welding.

Figure 16: Finished freehanded end of handle

Tig Welding. Only two parts required welding on the project. The first portion was the stem and handle. The stem was placed in the ½ inch recess in the handle to ensure the stem was square to the handle. The section portion that required welding was the penetrating unit to the bottom of the load cell housing. The unit was centered on the bottom of the housing and welded in place.

Wiring the Display and Load Cell. Because the load cell was unamped, meaning there was no original power supply, a power supply for the load cell had to be used. This supply had to be different than the supply for the display. In order to make the load cell function properly a resistor was placed on the positive supply from the 9 volt battery to create a 5 volt supply voltage. The size of the resistor was determined by testing the current of the load cell, which was 5mA, and then using Ohm's Law to determine that a minimum of an 800 ohm resistor was required. A 1K resistor was used in the system.

$$Ohm's\ Law: R = \frac{E}{I} = \frac{4v}{5mA} = 800\Omega$$

The load cell's output was in millivolts. The display required 9 volts to power the screen so no resistors were needed for the circuit. The positive signal was soldered to the positive output from the load cell and the ground was connected to the negative output allowing the display to read the millivolt reading (Figure 17).

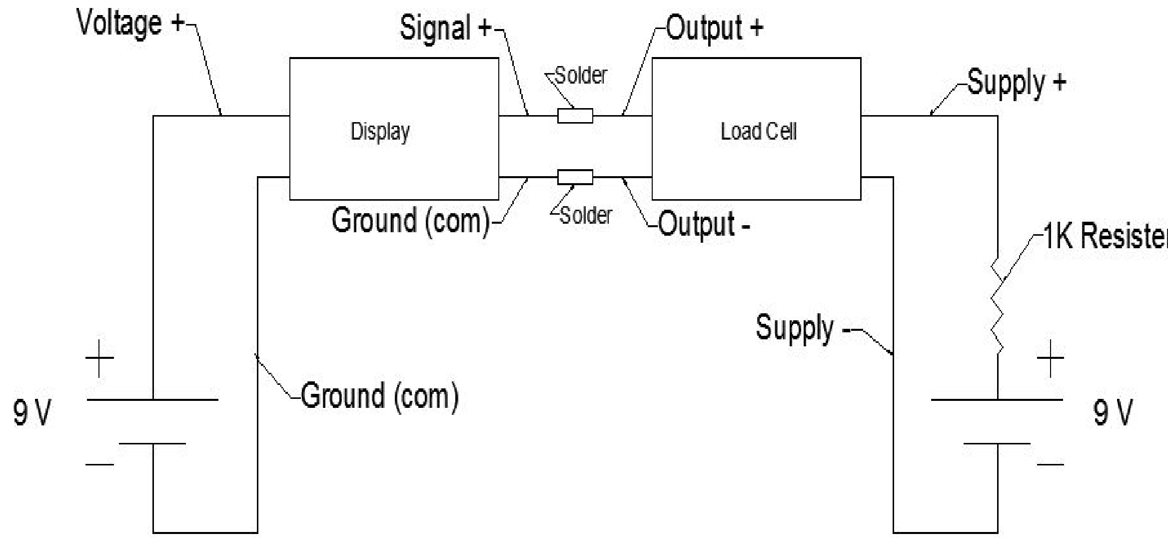

Figure 17: This figure shows the wiring for the circuit.

Testing Procedure

To make sure the unit was functioning properly, it was testing using a scale. The scale would measure the force in pounds produced by pushing the penetrometer into a piece of wood. A constant force was applied and compared to the table created for the results.

Field Testing. Once tested in the lab, the unit was tested out in the field to gather real data that would be used during tractor pull events. Soil was collected and then tested using the penetrometer. The depth penetrated for the tests was 5 inches. The penetrometer can be set at a specific depth depending on the stop setting. This test was used to compare lab testing with field data. Because the display unit will be mounted on the penetrometer, only one person will be required to do the testing.

Event Procedure. This procedure requires the tester to take measurements at 9 to 12 points on the track depending on soil variability. The spots on the track to be tested, as shown in Figure 18, allow the driver to pick a section of track that may have the most consistent soils. The data collected from the testing is to be used with the table created to assist with the recommended tire pressures. The pressure range uses data that has been accumulated over the last 11 years at different events. This range is 4 psi to 6.5 psi.

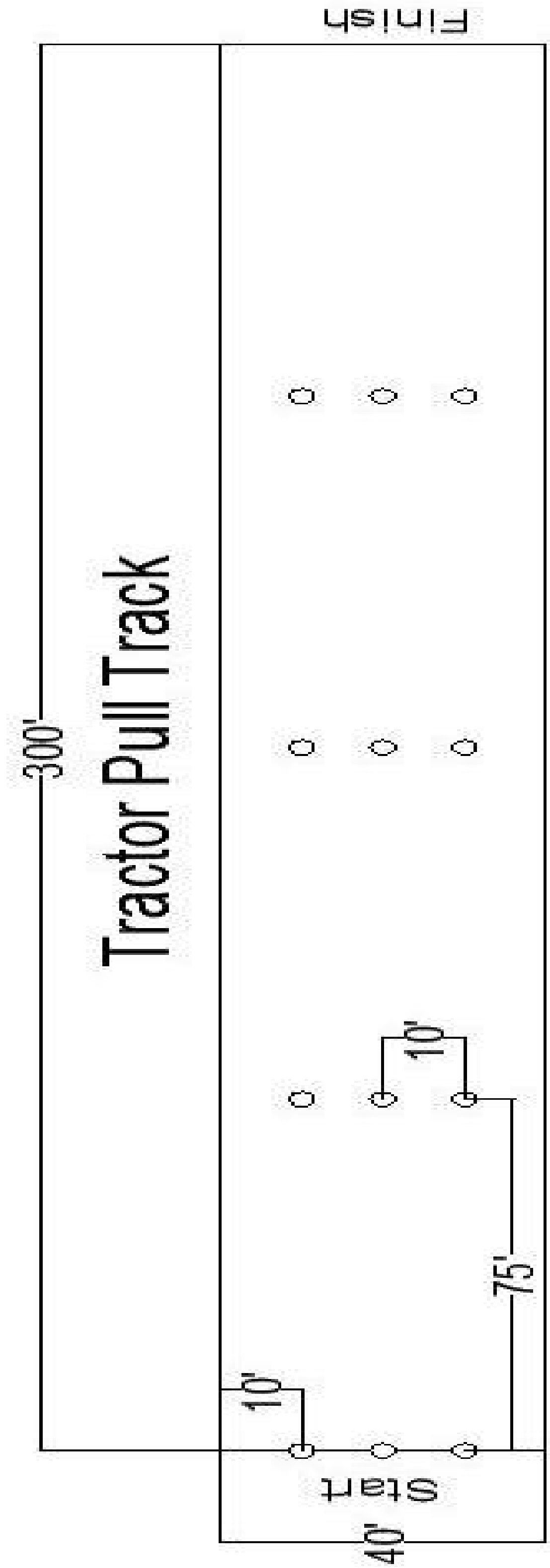

Figure 18: This figure shows the dimensions of the track. It also shows the different areas that the soil is to be tested.

RESULTS

Lab Testing

When the completed penetrometer was done (Figure 19), a series of 2 tests were conducted in the lab to make sure the unit was working properly. The tests measured the force applied. These values were compared to the values displayed on the digital display that were measured in millivolts. The results of the test are shown in Table 1. This test was used to calibrate the accuracy of the load cell and output reading on the display.

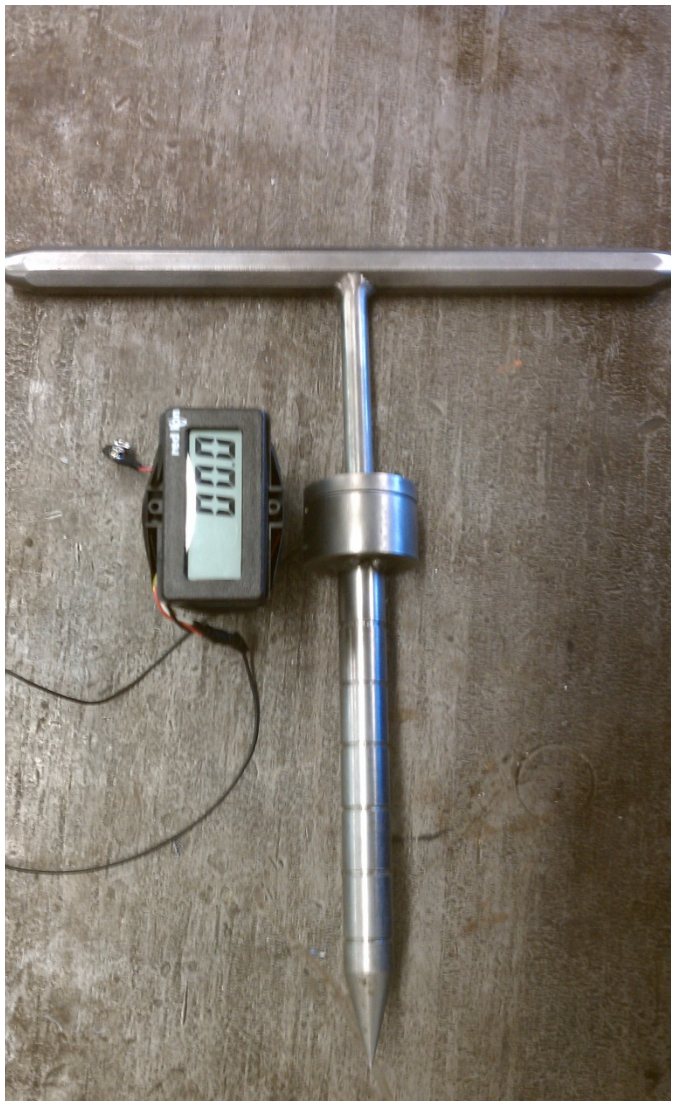

Figure 19: Completed penetrometer without the display mounted

Table 1: Initial test results from the lab tests

Measured (mV)	Factored (mV to lbs.)	Actual Measured (lbs.)	% Error
1.3	3.25	3.4	4.41
38.4	96	86	11.63
51.4	128.5	120	7.08

DISCUSSION

In order to make an accurate estimation more data needs to be gathered to compare tire pressure with performance of the tractor in order to develop a relationship.

A major component of the design that required more effort than the other parts was the wiring of the digital read out and load cell. The issue faced was a mysterious 2 volt reading that would read out on the display when hooked up. This was due to the single power supply using 2 common grounds that connected to both the load cell output and the display signal. The way this issue was resolved was to make separate power supplies for the load cell and display unit. This eliminated the 2 volt current showing up on the display.

Another change in the design occurred when the handle was initially placed in the cap unit and did not fit snuggly. The solution to the problem was to fabricate a bushing that would eliminate the slop of the handle.

RECOMMENDATIONS

In order to make this project valid, the Penetrometer should be used during the Tractor Pull season at the various events. Data needs to be collected at each event, analyzed, and acted upon. The performance of the tractor can then be evaluated to determine whether or not the recommended tire pressure helped with performance or hurt the performance. After a season's worth of data has been collected, alterations to the table can be made if necessary to help improve the performance of the tractor.

Recommended Procedure

The penetrometer should travel with the Tractor Pull team over the course of the summer to different events and be used to measure the Cone Index of the soils.

Pre-Pull Procedure. The event testing procedure should be used for the pre-pull data collection. This means that data points along the track need to be tested and recorded. The average force at the data points needs to then be determined. The average force applied should be recorded as well as the soil conditions for the track. The tire pressure should then be set according to the log book records for that location or personal recommendation.

Post Pull Procedure. After the pull, the performance of the tires needs to be analyzed. The analysis should determine whether or not the tires performed as desired. If the tires did not perform as intended then a recommendation needs to be made to adjust the tire pressure up or down. All of this information should be recorded into the data table (Table 4). This table will be incorporated into the log book. The corrected tire pressure is the pressure that would have been used if there were a second run at the same location.

Table 2: A mock table of data collected and analyzed for referencing.

Event	Date	Soil Condition	Pene. Reading Average (mV)	Pene. Force (lbs.)	Performance of Tires	Corrected pressure (psi)
Pull # 1	4/16/11	Compacted Pasture	70	175	Good	4
Pull # 2	5/30/11	Rodeo Arena	86	215	ok	5
Pull # 3	5/23/11	soft top with hard ground underneath	70	175	ok	5.5
Pull # 4	5/25/11	Hard compacted track	95	237.5	ok	6
…	.	.	.	.	.	.

Once the data is recorded on the table the information will be logged into the data sheet using Microsoft Excel. The information will be plotted on to a graph (Figure 20).

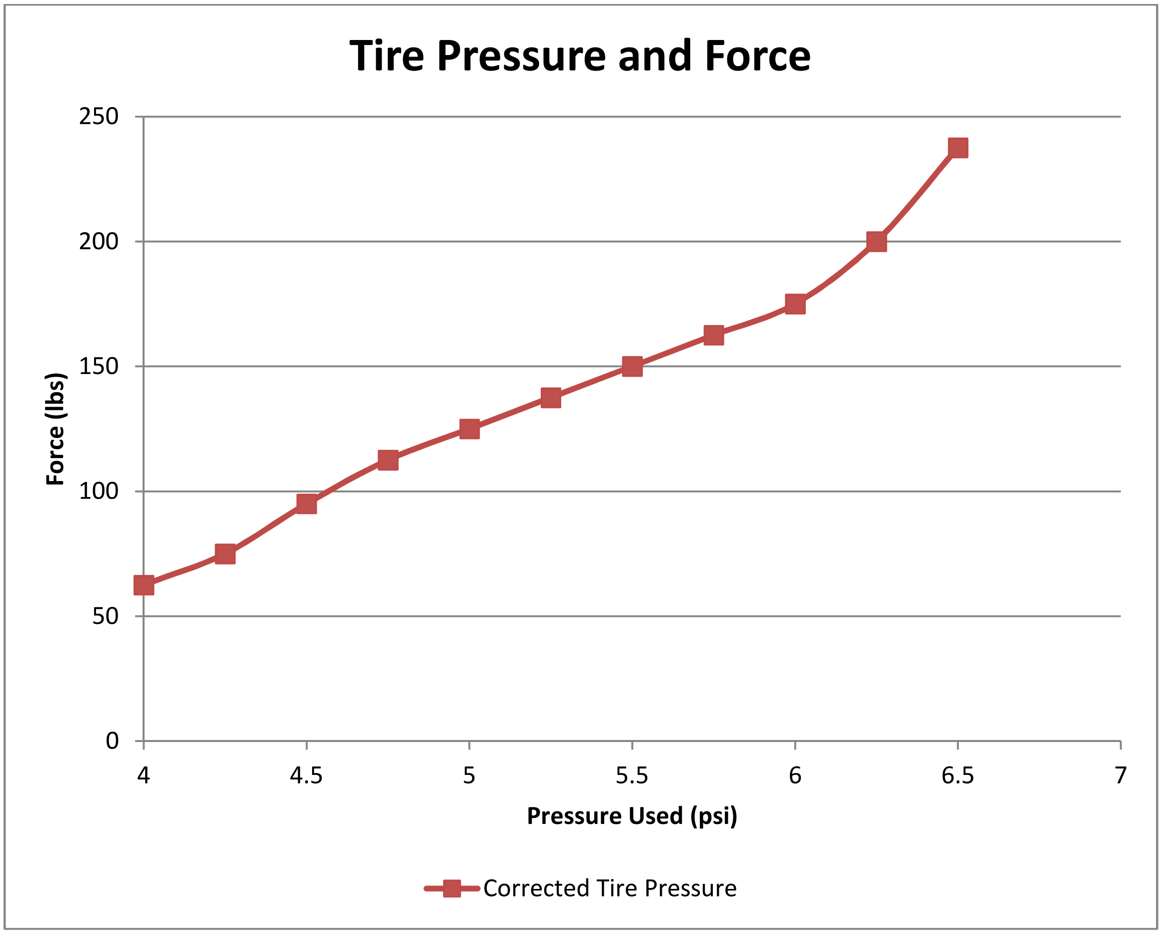

Figure 20: Mock graph showing potential data results

Once the pull season is over the tire data needs to be evaluated. The graph should conclude a line of best fit for forces and pressures. This line should be the optimal tire pressure performance based off of the soil cone index. The measurements would then need to be used for the future pulls. When this table is made, members of the tractor pull team will only need to measure the force required to penetrate the soil. The reading will allow the team to determine the pressure based off of the graph of data. If the data from the penetrometer are in between 2 points, the value on the line on the graph will be used.

Because the initial testing was done for the tractor “Mustang Fever” and its specific tires, another table with recommended tire pressure would need to be made to accommodate the needs of tractors using the tires “Firestone Puller 2000’s”.

To avoid faulty wiring and other potential electrical failures, a mechanical read out using a pressure gauge or spring read out could be used to measure the forces applied to the soils.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR

HOW PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR

ASM PROJECT REQUIREMENTS

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The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving. This project addresses these issues as follows.

Application of Agricultural Technology. The project will involve the application of problem solving, design procedures, mechanical and electrical systems, and fabrication technologies.

Application of Business and/ or Management Skills. Cost analysis was used during the project to help minimize money spent while being able to produce a quality product.

Quantitative, Analytical Problem Solving. Quantitative problem solving will include the design of a soil testing device used to increase performance of a modified pulling tractor.

Capstone Project Experience

The ASM senior project must incorporate knowledge and skills acquired in earlier coursework (Major, Support, and/ or GE courses). This project incorporates knowledge/ skills from these key courses.

- BRAE 129 Lab Skills and Safety
- BRAE 133 Engineering Design Graphics
- BRAE 142 Ag Power and Machinery
- BRAE 151 CAD for Ag Engineering
- BRAE 152 3D Solids Modeling
- BRAE 203 Ag Systems Management
- BRAE 301 Hydraulic/Mechanical Power Systems
- BRAE 324 Principles of Ag Electrification
- BRAE 342 Ag Materials
- BRAE 343 Mechanical Systems Analysis
- BRAE 344 Fabrication Systems
- BRAE 418/419 Ag Systems Management
- ENG 148 Reasoning, Argumentation, and Professional Writing
- SS 121 Introductory Soil Science

ASM Approach

Agricultural Systems Management involves the development for solutions to technological, business or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas are common features of this type of problem solving. This project addresses these issues as follows.

Systems Approach. The project involves testing and analysis of data to increase performance of a piece of equipment.

Interdisciplinary Features. The project includes aspects of mechanical systems and design, along with problem solving and data analysis.

Specialized Agricultural Knowledge. The project requires specialized knowledge of modified pulling tractors and an understanding of Soil Cone Index.

APPENDIX B

<u>INDIVIDUAL PARTS DRAWINGS</u>

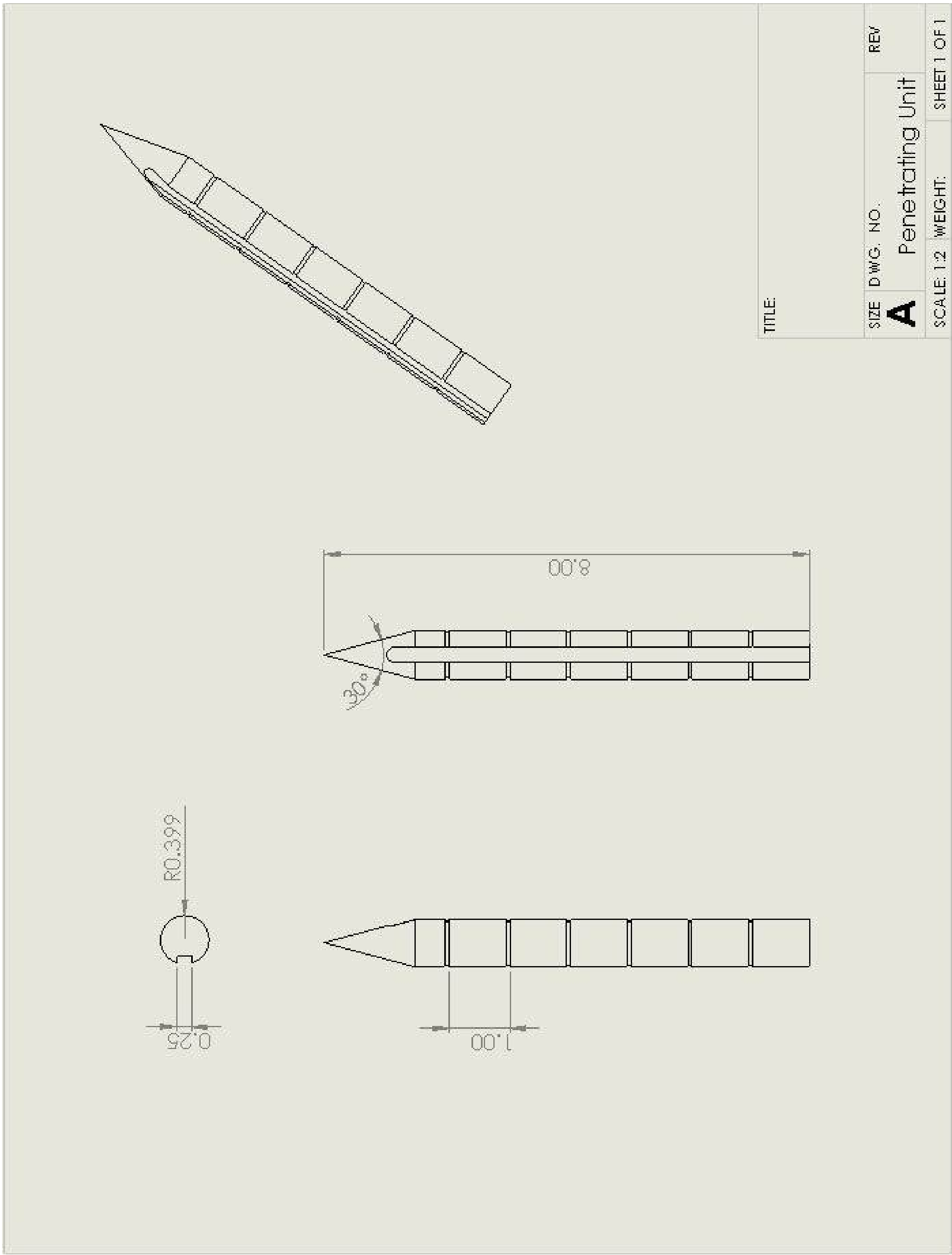

Figure 21: Penetrating Unit Part Design

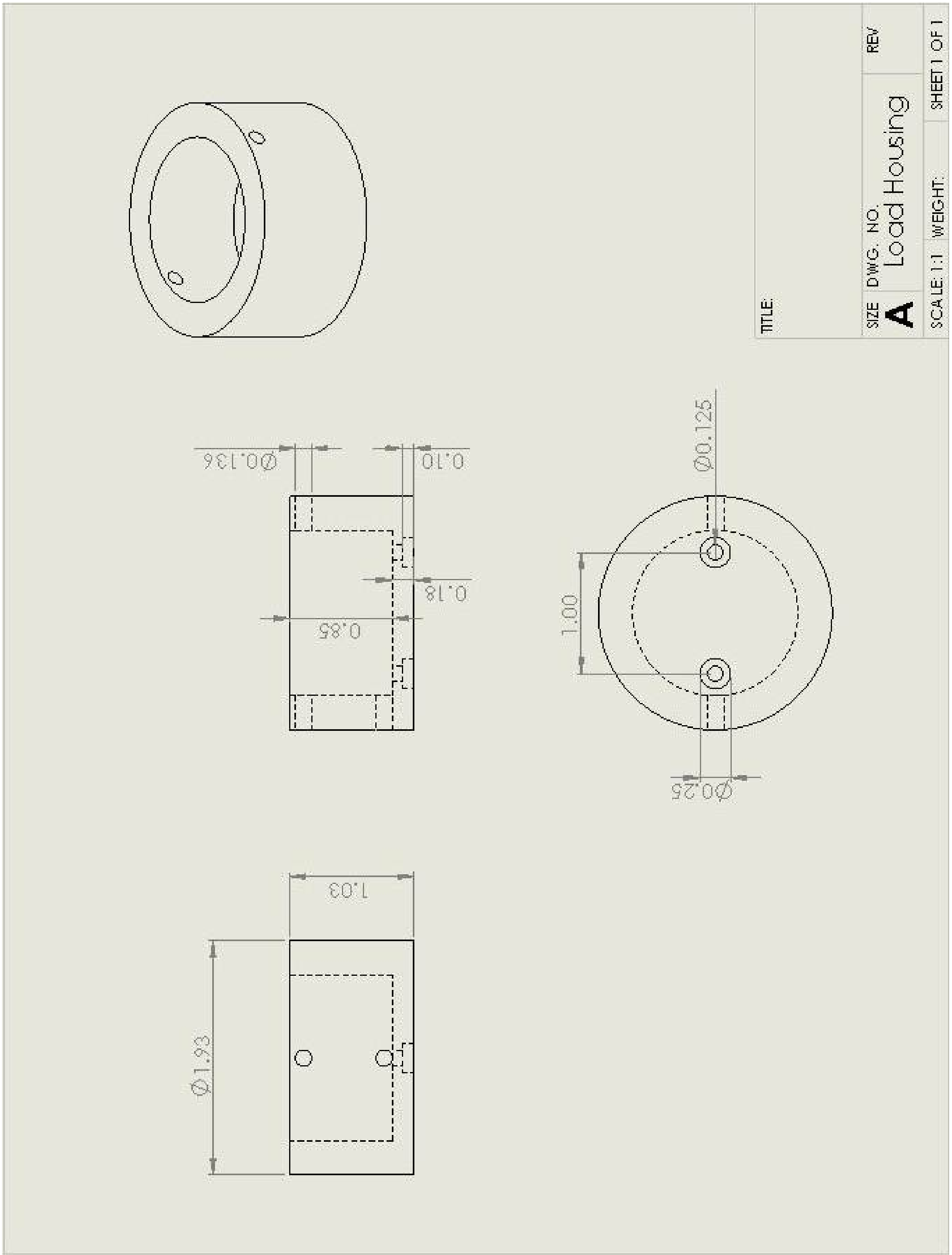

Figure 22: Load Cell Housing

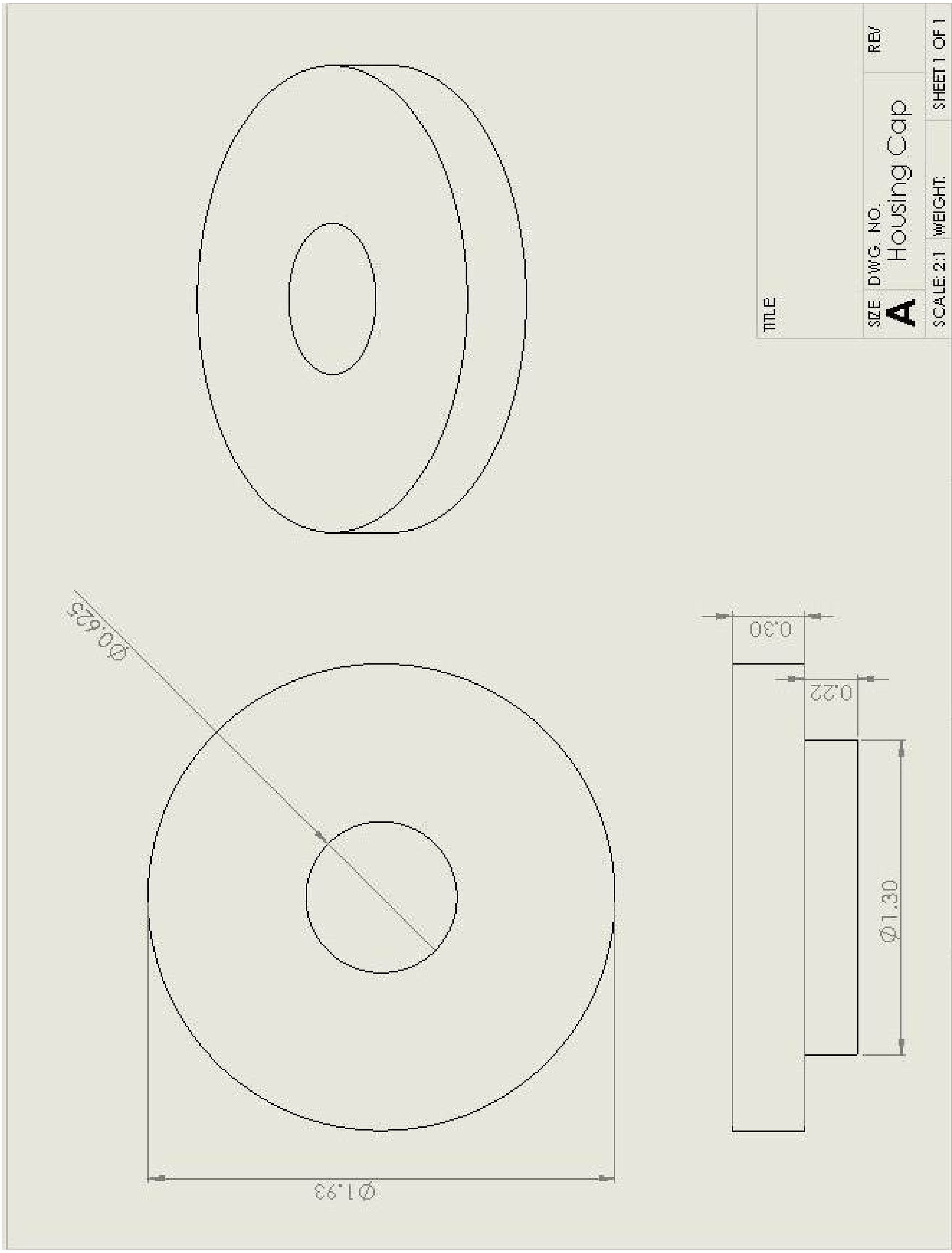

Figure 23: Housing Unit Cap

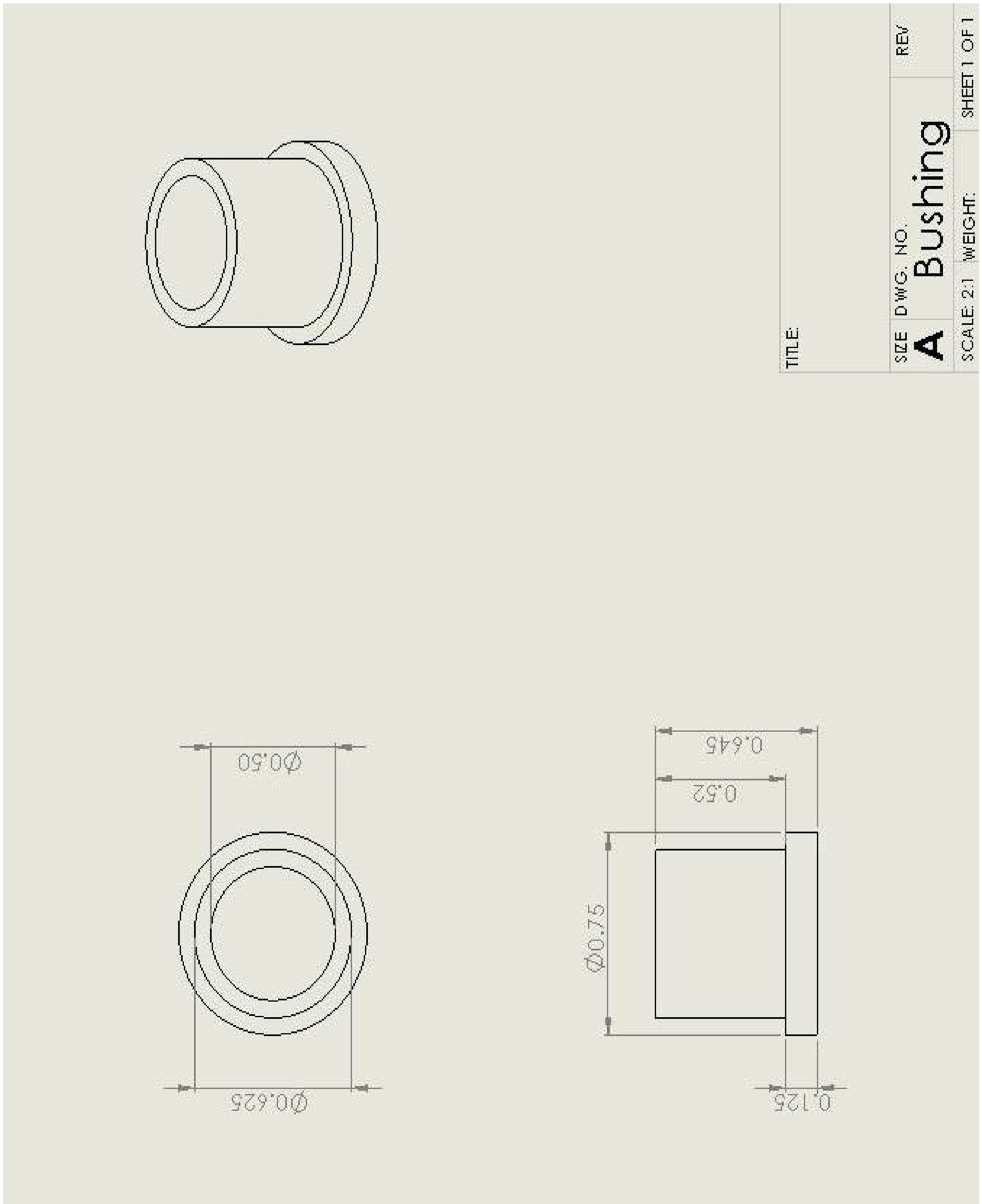

Figure 24: Bushing for Cap

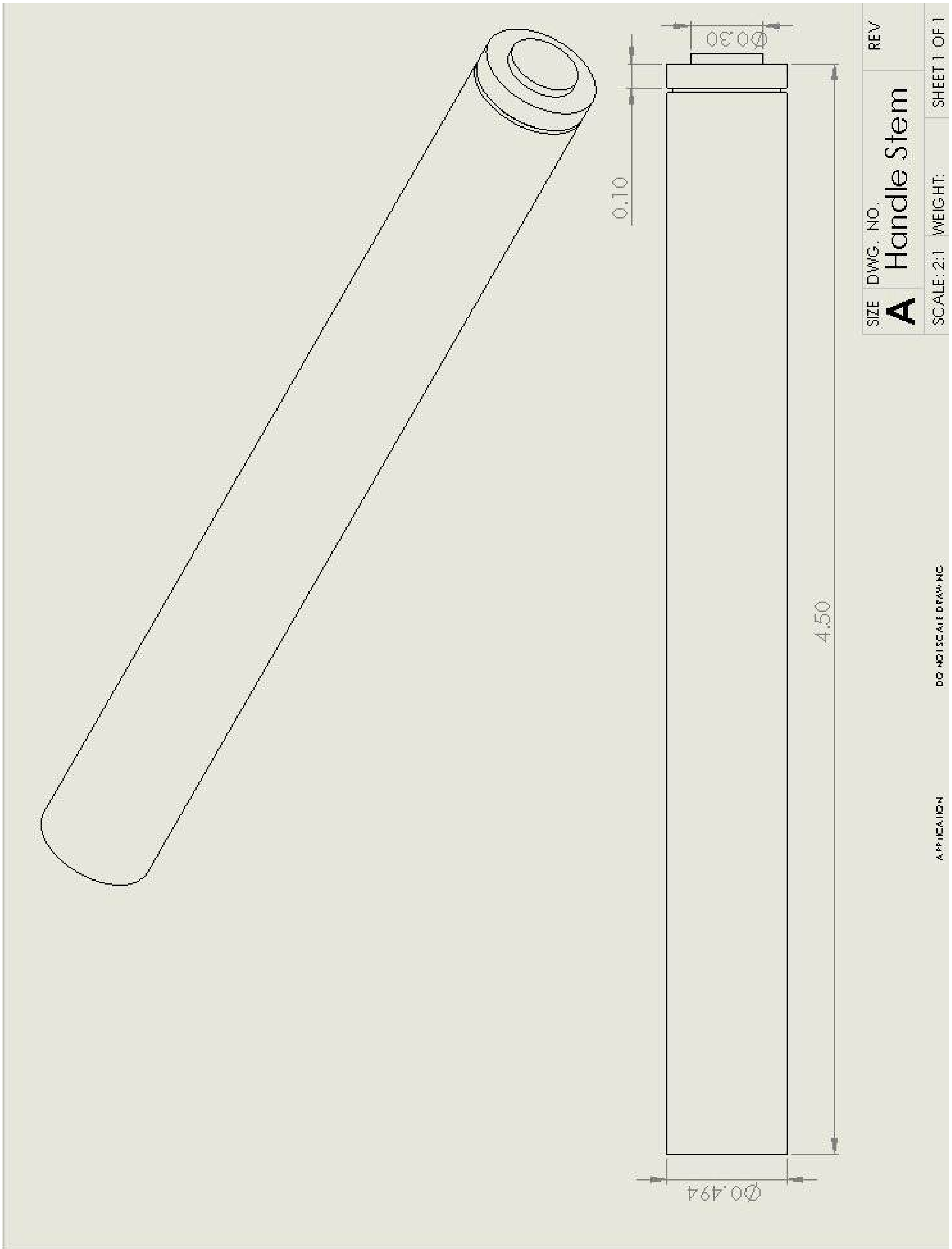

Figure 25: Handle Stem

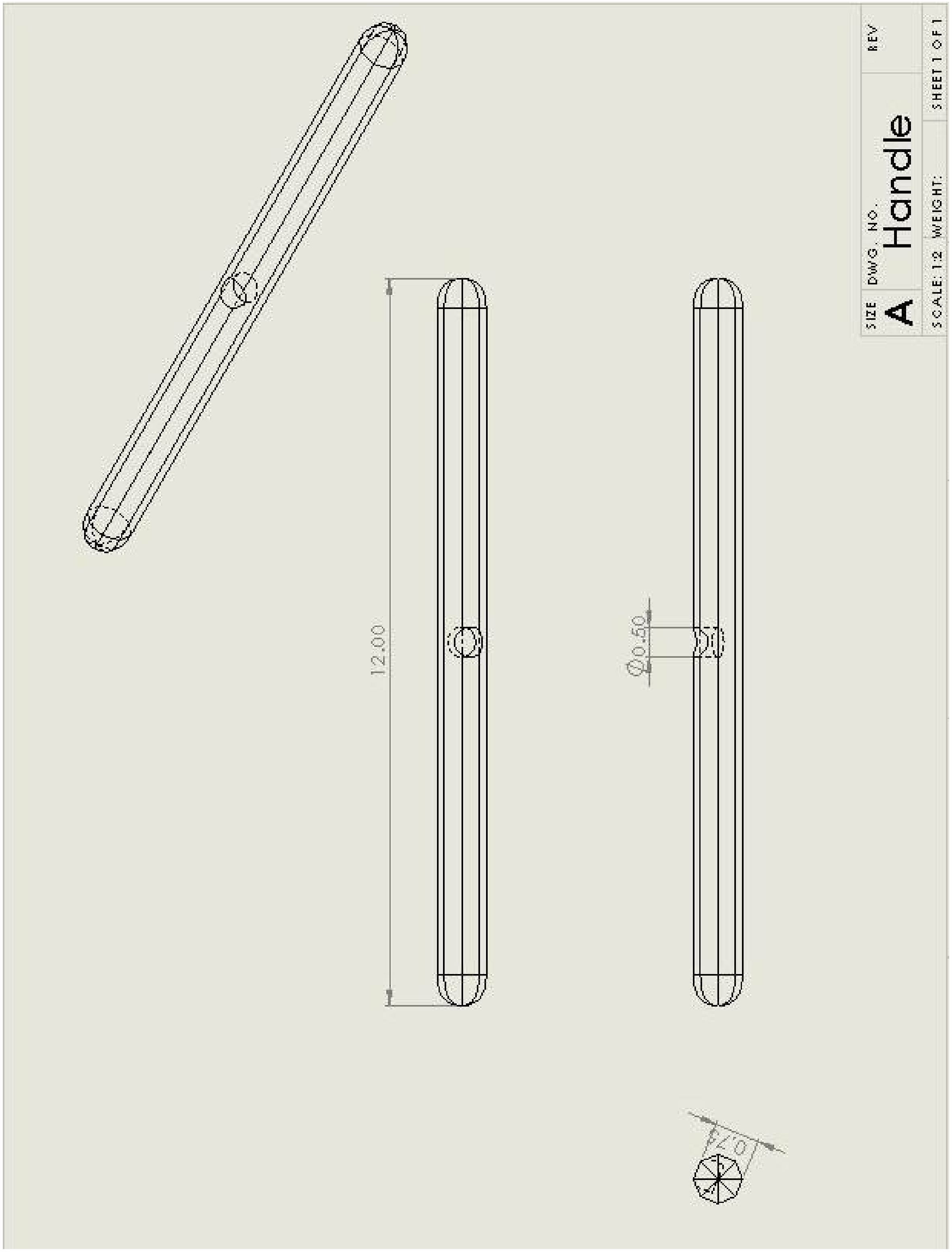

Figure 26: Handle for Penetrometer